US-PAT-NO: 5568568

DOCUMENT-IDENTIFIER: US 5568568 A

TITLE: Pattern recognition apparatus

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Detailed Description Text - DETX (18):
Referring now to FIG. 2, there is shown a flowchart of the operation of the comparison pixel determination section 31 in the pattern recognition apparatus 30 of FIG. 1. In a first step designated by block 101 (following a "start" block 100), data relating to the 160 variant reference patterns (discussed hereinabove) is read out of a memory (not shown in FIG. 1) and provided as an input to the comparison pixel determination section 31. In a second step designated by block 102, the probability [P.sub.i of equation (1)]is calculated for each pixel within a **frame** 16 (of FIG. 6) that contains a reference pattern being black or white. In a third step designated by block 103, the **probability of each pixel** being black or white, as calculated in block 102, is used to calculate the information content entropy

value H, using equation (1). The function of block 103 is better understood from FIG. 4.

US005568568A

United States Patent [19]

Takizawa et al.

[11] Patent Number: 5,568,568

[45] Date of Patent: Oct. 22, 1996

[54] **PATTERN RECOGNITION APPARATUS**

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[73] Assignee: **Eastman Kodak Company**, Rochester, N.Y.

[21] Appl. No.: **824,277**

[22] Filed: **Jan. 23, 1992**

[30] **Foreign Application Priority Data**

Apr. 12, 1991 [JP] Japan 3-080243

[51] **Int. Cl.**[6] **G06K 9/62**

[52] **U.S. Cl.** **382/220**; 382/160

[58] **Field of Search** 382/14, 15, 30

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Assistant Examiner—Chris Kelley
Attorney, Agent, or Firm—Marc A. Rossi; Rossi & Associates

[57] **ABSTRACT**

A pattern recognition system is disclosed that uses a predetermined minimal number of comparison pixels in a pattern recognition process for input image recognition. For each pixel within a prescribed frame, a probability of the existence of a reference pattern is calculated by a probability calculation means. These probability values are used by a entropy calculation means to calculate pixel entropy values. Pixels with a high entropy value are then extracted and designated as comparison pixels for the pattern recognition operation. Comparison means compares these comparison pixels with corresponding pixels of an image pattern, and determines which of the reference patterns has a highest probability of being the image pattern.

6 Claims, 8 Drawing Sheets

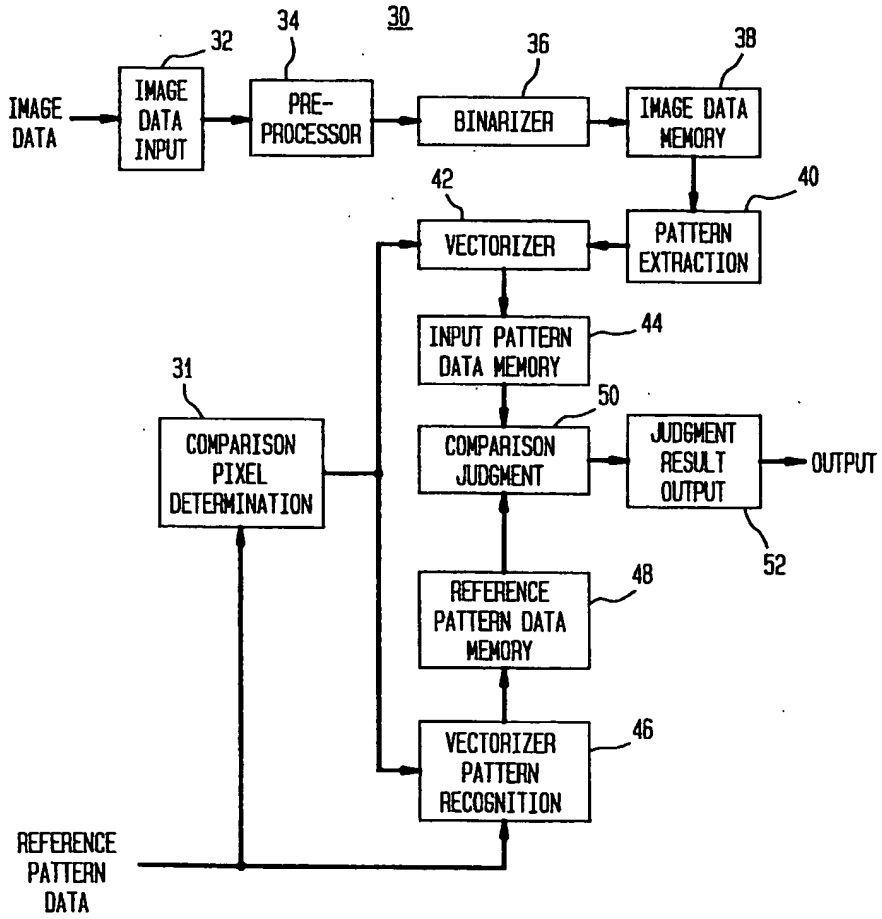


FIG. 1

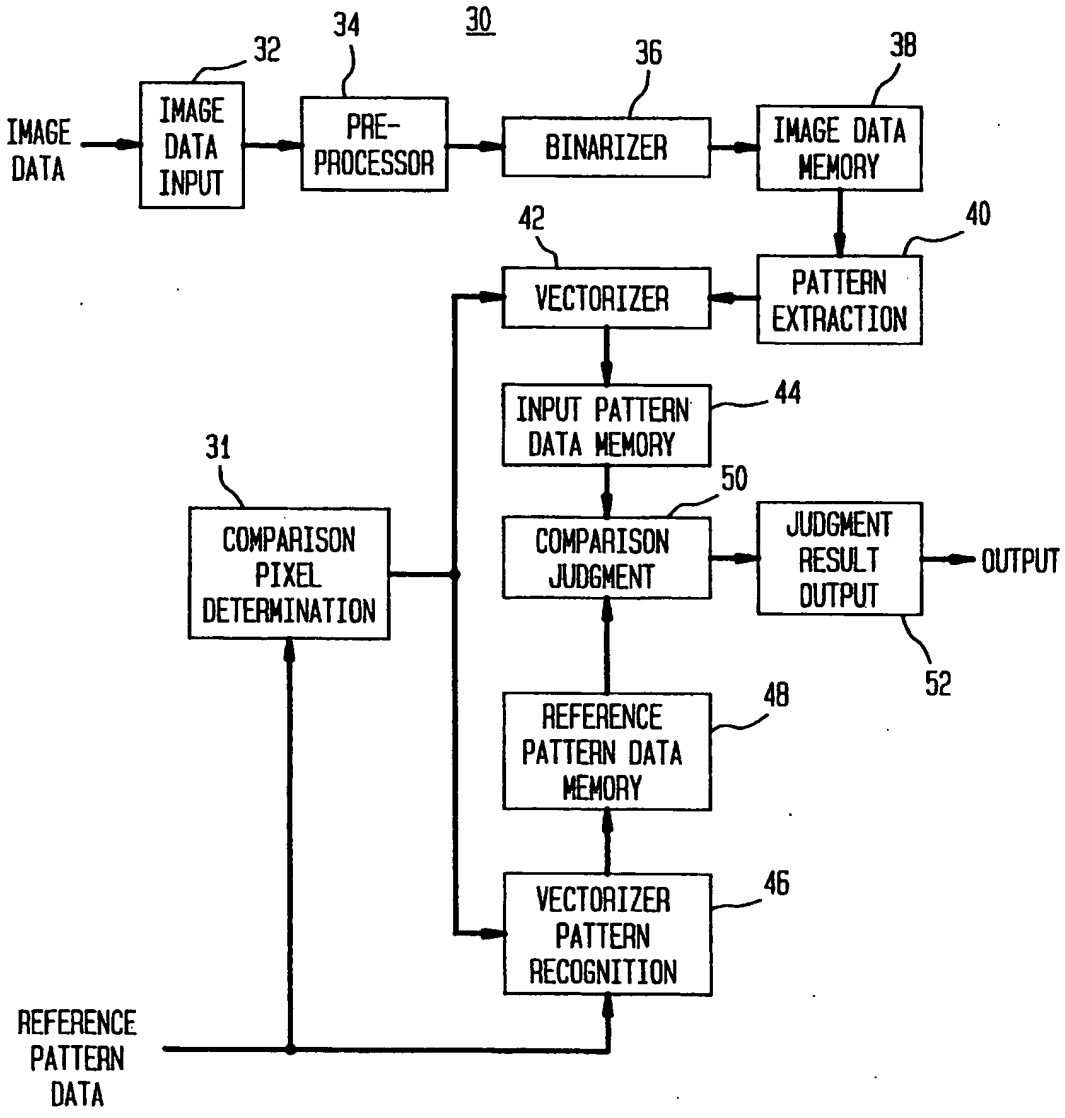

30
IMAGE DATA
32
IMAGE DATA INPUT
34
PRE-PROCESSOR
36
BINARIZER
38
IMAGE DATA MEMORY
40
PATTERN EXTRACTION
42
VECTORIZER
44
INPUT PATTERN DATA MEMORY
31
COMPARISON PIXEL DETERMINATION
50
COMPARISON JUDGMENT
JUDGMENT RESULT OUTPUT
OUTPUT
52
48
REFERENCE PATTERN DATA MEMORY
46
VECTORIZER PATTERN RECOGNITION
REFERENCE PATTERN DATA

FIG. 2

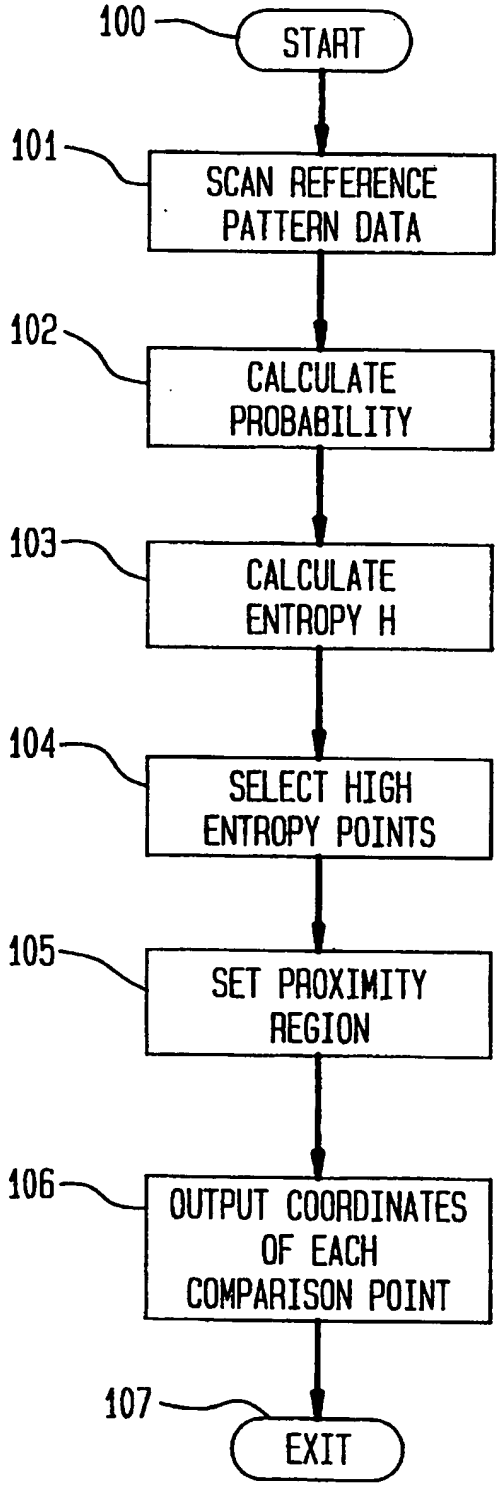

100
START
101
SCAN REFERENCE PATTERN DATA
102
CALCULATE PROBABILITY
103
CALCULATE ENTROPY H
104
SELECT HIGH ENTROPY POINTS
105
SET PROXIMITY REGION
106
OUTPUT COORDINATES OF EACH COMPARISON POINT
107
EXIT

FIG. 3

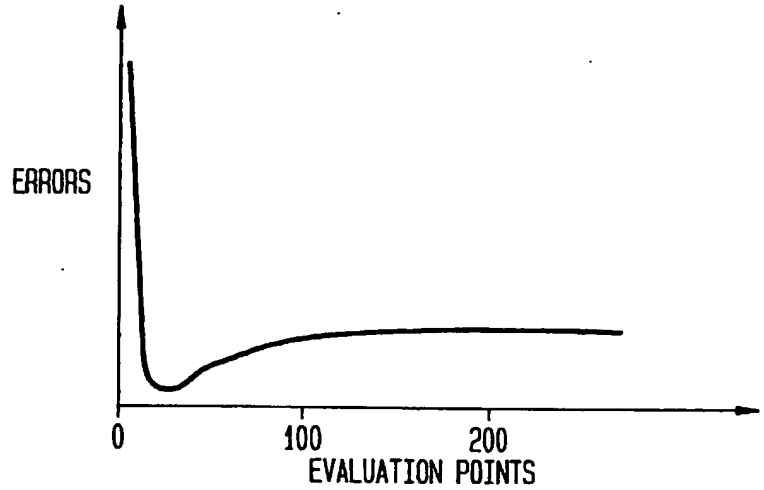


FIG. 4

00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00	00
00	00	05	13	25	34	47	53	61	58	61	54	44	31	13	00	00	00
00	13	51	81	92	100	99	94	87	72	71	91	99	89	61	23	00	00
13	38	78	98	96	90	87	77	56	23	13	47	78	100	89	58	10	00
13	53	95	96	90	90	81	59	10	00	05	38	67	89	98	73	13	00
13	40	96	96	92	88	77	70	69	61	64	65	71	90	100	81	31	00
10	41	93	100	99	99	99	100	100	100	99	98	90	96	100	86	43	00
13	54	92	98	99	99	99	96	96	92	92	97	98	99	100	84	43	00
13	58	88	98	99	98	100	96	93	87	92	99	99	100	100	83	36	00
13	59	86	99	100	99	100	100	97	97	99	100	99	100	97	80	31	00
10	53	84	99	99	100	100	100	100	99	95	91	93	100	94	77	29	00
10	49	85	99	99	100	99	100	99	97	80	72	72	98	92	75	34	00
10	53	86	98	99	100	100	99	96	88	68	63	63	90	98	77	23	00
13	60	90	100	100	99	100	100	99	96	81	70	73	90	100	86	29	00
10	70	94	100	100	100	99	96	96	100	99	92	85	90	98	94	42	00
13	65	98	98	100	100	99	95	94	95	97	100	92	89	95	97	51	00
13	70	97	99	100	98	95	93	92	89	93	99	95	89	93	99	49	00
17	76	98	100	100	97	90	79	83	89	93	99	97	93	96	100	49	00
20	70	98	100	100	95	82	73	80	89	96	100	96	93	99	98	38	00
13	65	97	99	99	96	79	84	87	95	100	97	87	96	100	90	34	00
13	64	98	100	100	98	100	100	99	99	89	78	80	97	99	72	29	00
17	58	96	99	96	82	75	76	84	79	64	64	82	99	91	56	10	00
13	43	87	100	96	75	75	75	83	86	68	78	95	98	75	31	13	00
10	23	63	86	100	92	77	82	91	94	91	97	97	79	49	17	05	00
00	13	17	45	73	87	96	95	93	92	87	81	61	41	13	10	00	00
00	05	10	10	13	13	26	23	13	13	10	10	13	00	05	00	00	00

(x 10^{-2})

200

FIG. 5

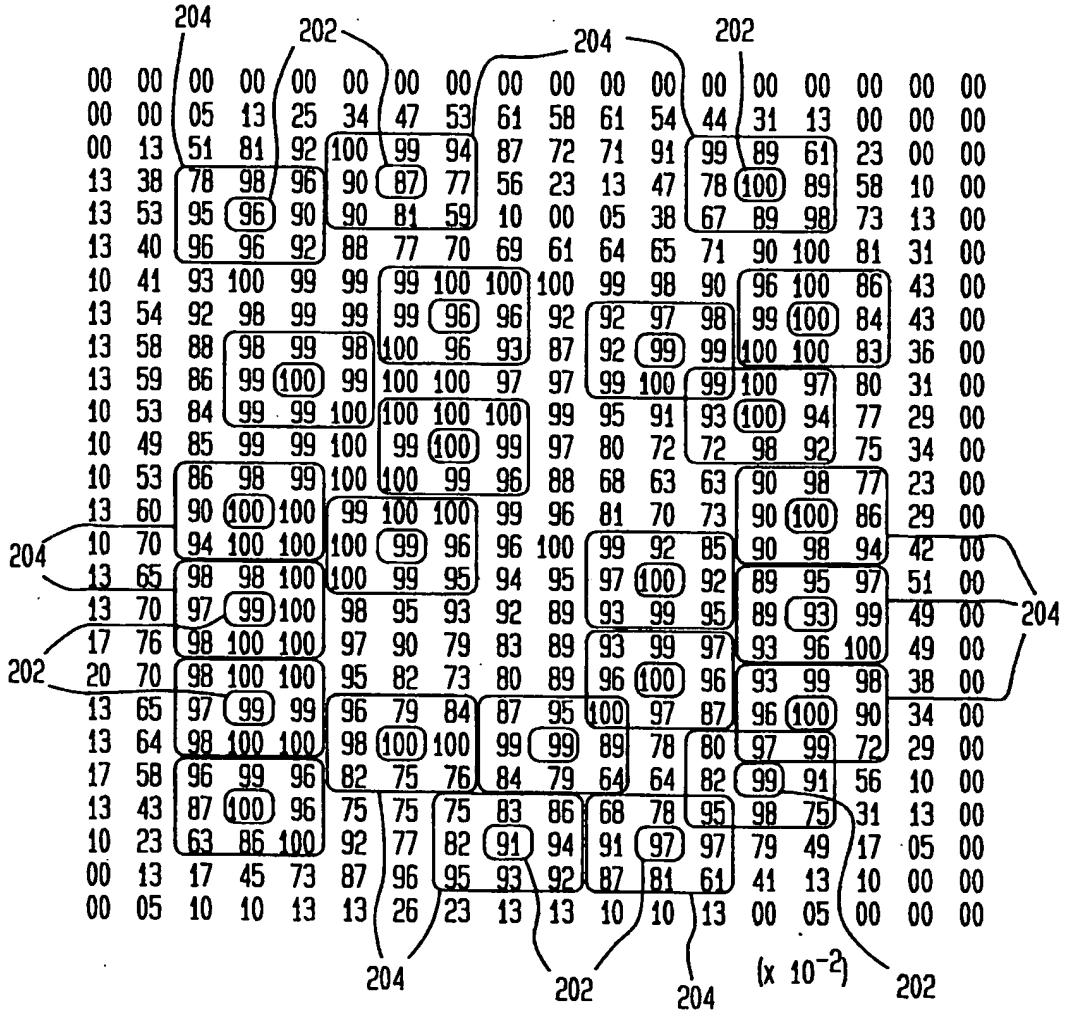

204
202
204
202
00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
00 00 05 13 25 34 47 53 61 58 61 54 44 31 13 00 00 00
00 13 51 81 92 100 99 94 87 72 71 91 99 89 61 23 00 00
13 38 78 98 96 90 87 77 56 23 13 47 78 100 89 58 10 00
13 53 95 96 90 90 81 59 10 00 05 38 67 89 98 73 13 00
13 40 96 96 92 88 77 70 69 61 64 65 71 90 100 81 31 00
10 41 93 100 99 99 99 100 100 100 99 98 90 96 100 86 43 00
13 54 92 98 99 99 99 96 96 92 92 97 98 99 100 84 43 00
13 58 88 98 99 98 100 96 93 87 92 99 99 100 100 83 36 00
13 59 86 99 100 99 100 100 97 97 99 100 99 100 97 80 31 00
10 53 84 99 99 100 100 100 100 99 95 91 93 100 94 77 29 00
10 49 85 99 99 100 99 100 99 97 80 72 72 98 92 75 34 00
10 53 86 98 99 100 100 99 96 88 68 63 63 90 98 77 23 00
13 60 90 100 100 99 100 100 99 96 81 70 73 90 100 86 29 00
204 10 70 94 100 100 100 99 96 96 100 99 92 85 90 98 94 42 00
13 65 98 98 100 100 99 95 94 95 97 100 92 89 95 97 51 00
13 70 97 99 100 98 95 93 92 89 93 99 95 89 93 99 49 00 204
17 76 98 100 100 97 90 79 83 89 93 99 97 93 96 100 49 00
202 20 70 98 100 100 95 82 73 80 89 96 100 96 93 99 98 38 00
13 65 97 99 99 96 79 84 87 95 100 97 87 96 100 90 34 00
13 64 98 100 100 98 100 100 99 99 89 78 80 97 99 72 29 00
17 58 96 99 96 82 75 76 84 79 64 64 82 99 91 56 10 00
13 43 87 100 96 75 75 75 83 86 68 78 95 98 75 31 13 00
10 23 63 86 100 92 77 82 91 94 91 97 97 79 49 17 05 00
00 13 17 45 73 87 96 95 93 92 87 81 61 41 13 10 00 00
00 05 10 10 13 13 26 23 13 13 10 10 13 00 05 00 00 00
204
202
204
(x 10^-2)
202

FIG. 6

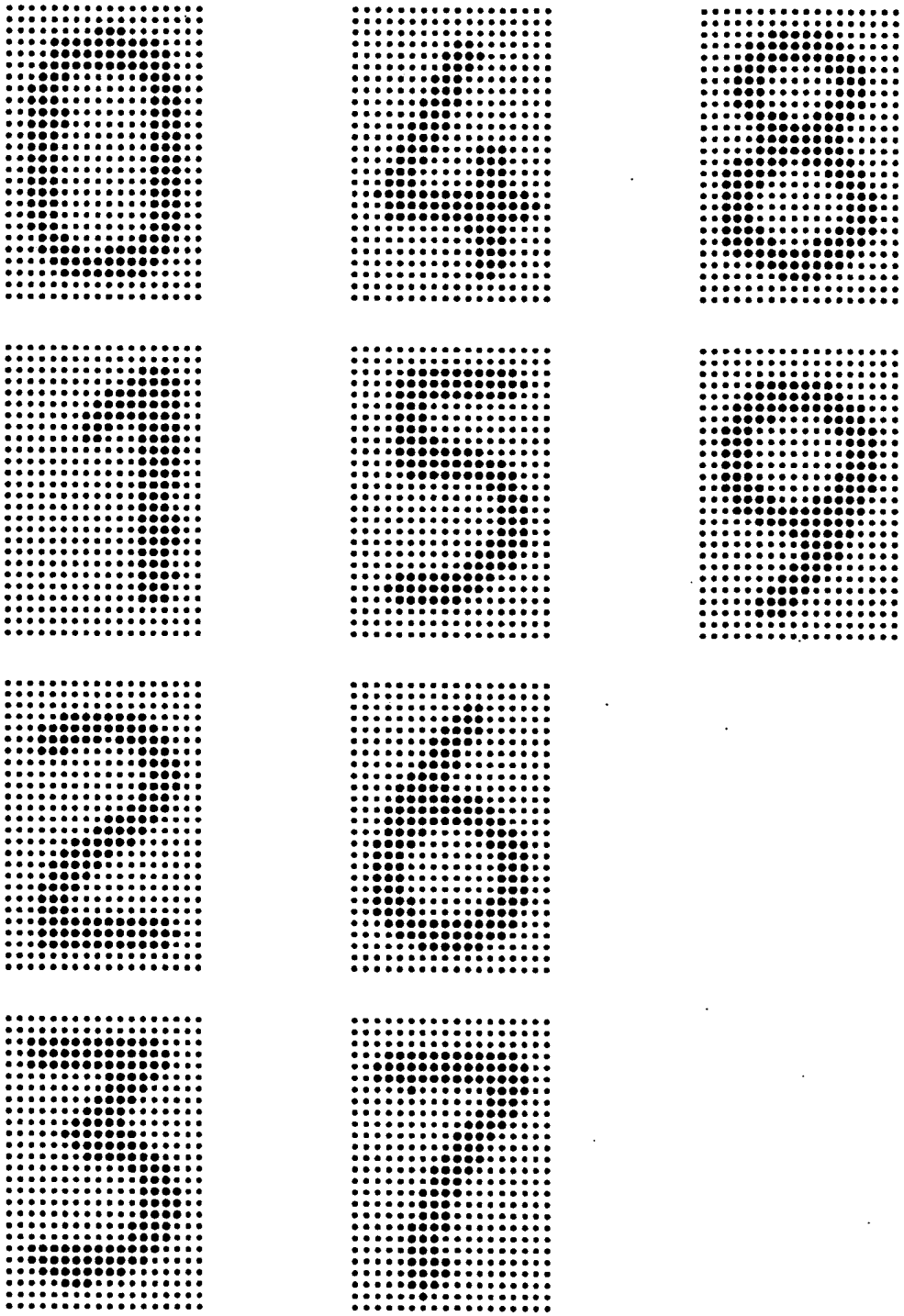


FIG. 7

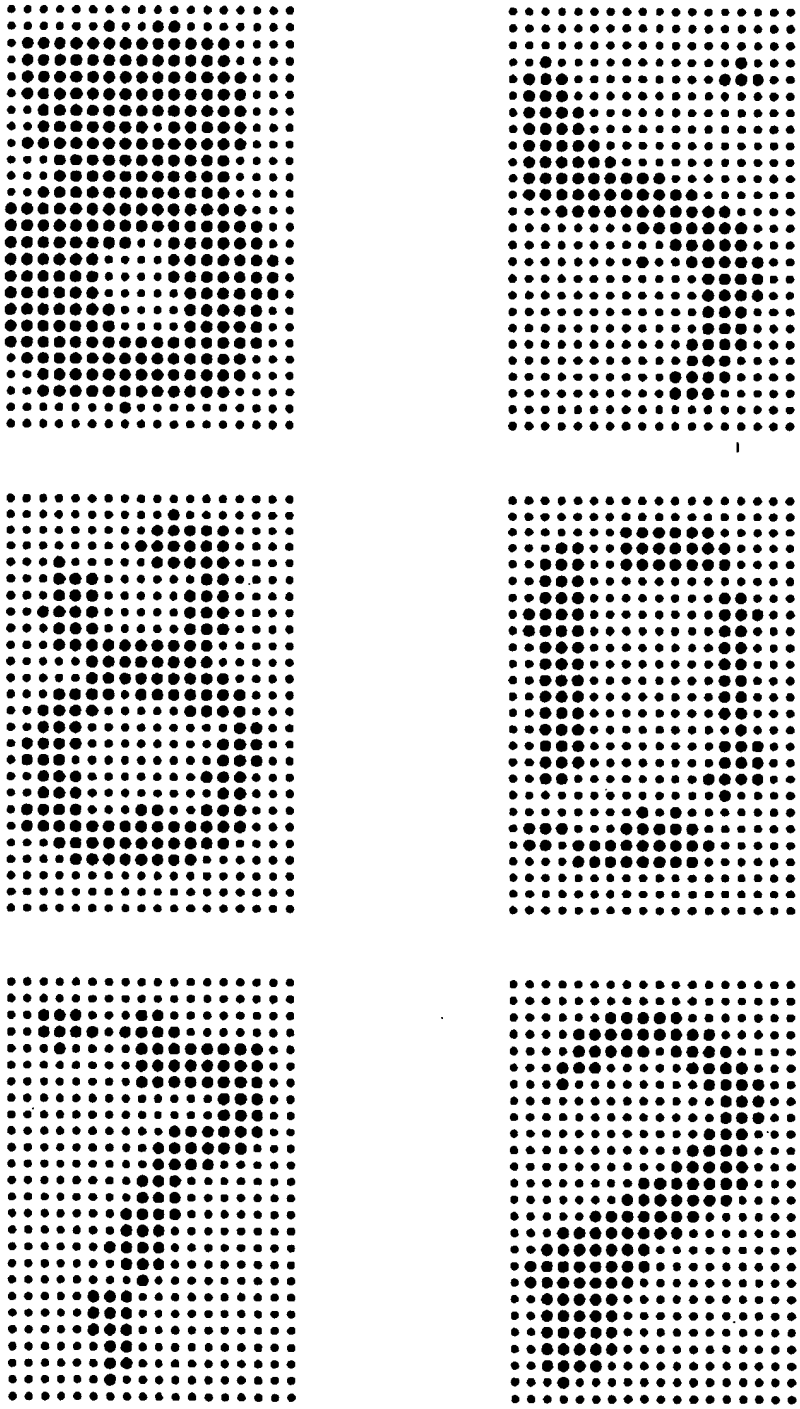


FIG. 8A

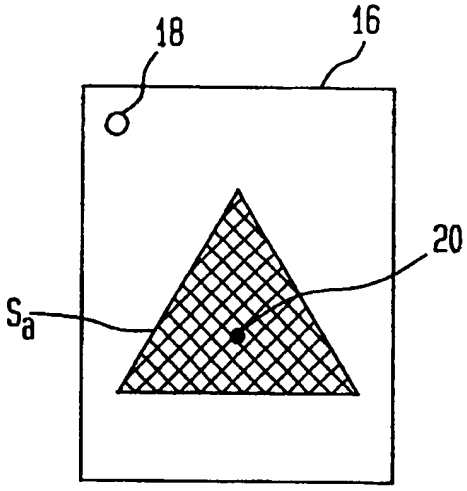


FIG. 8B

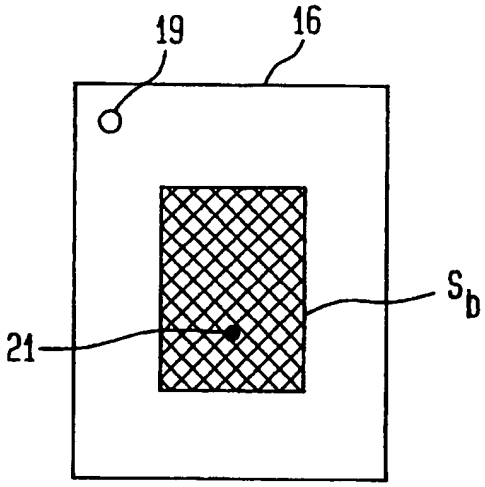


FIG. 8C

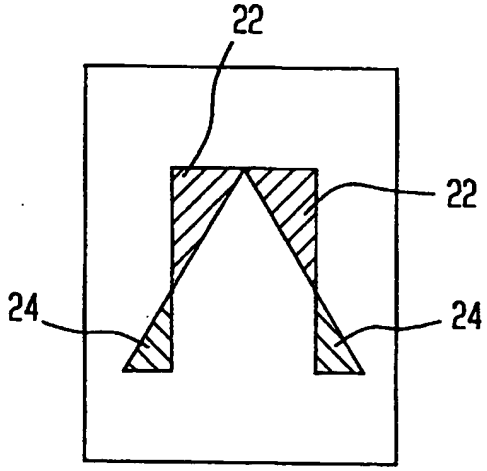
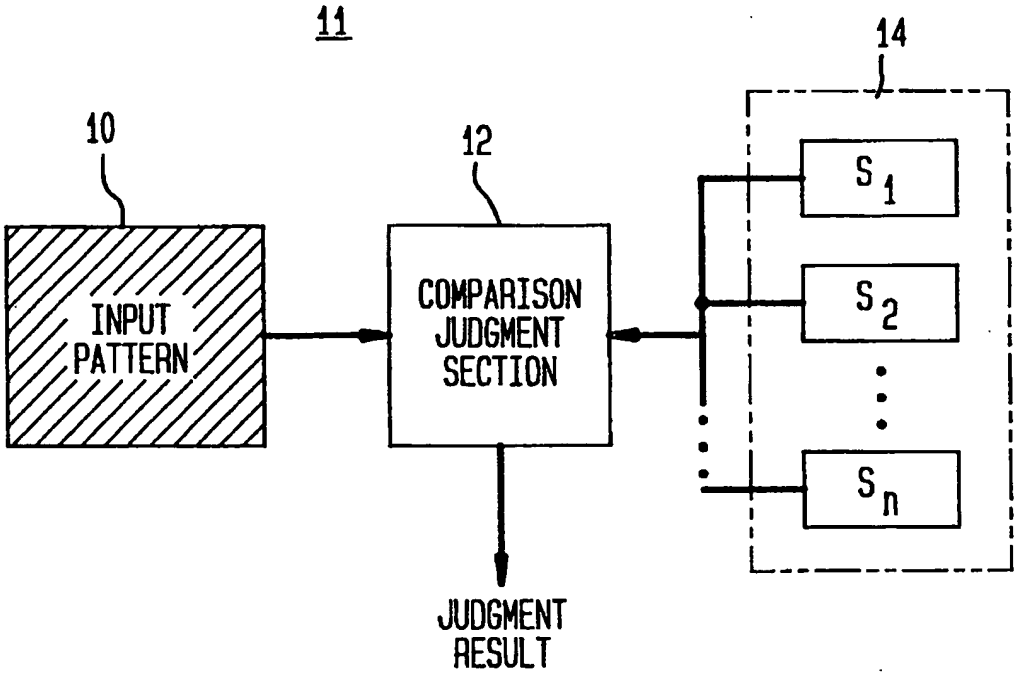


FIG. 9
(PRIOR ART)



PATTERN RECOGNITION APPARATUS

FIELD OF THE INVENTION

The present invention relates to a pattern recognition apparatus that judges an input pattern on the basis of a comparison of the input pattern with a plurality of registered reference patterns.

BACKGROUND OF THE INVENTION

Pattern recognition apparatuses are known in the prior art for optically reading characters and patterns, and are utilized in information processing. In recent years, the need for more sophisticated information processing and the processing of more complex information has led to a demand in various fields for pattern recognition apparatuses that offer higher recognition rates.

Referring now to FIG. **9**, there is shown a block diagram illustrating a basic processing principle of a conventional (prior art) pattern recognition apparatus **11** comprising an input pattern **10**, a comparison judgment section **12**, and a registration section **14** (shown within a dashed line rectangle) which is adapted to store a plurality of reference patterns S_1 to S_n. In such prior art pattern recognition apparatus **11**, the input pattern **10** is (a) scanned by a charge-coupled device (CCD) (not shown) or other such means, (b) subjected to prescribed preprocessing (not shown), and (c) then inputted to a comparison judgement section **12**. Preprocessing refers to the removal of noise components, image rotation, and other such adjustments. Prior to being inputted to the comparison judgement section **12**, the input pattern **10** is first binarized (not shown), and then is inserted into a prescribed frame (not shown) that defines the limits of the data of the input pattern **10**. The registration section **14** stores the plurality of reference patterns S_1 to S_n against which the input pattern **10** is compared in the comparison judgment section **12**. Each of the boundaries of a frame corresponding to the above-described prescribed frame.

The comparison judgment section **12** judges which of the reference patterns S_1 to S_n is most similar to the input pattern **10** and then generates an output representative of the outcome of such judgment. In making such judgment, all pixels in a frame form points of comparison for a process of comparing the input pattern with the reference patterns. The number of matching points for each of the comparisons is mathematically processed as, for example, by applying a correlation function or the like. The reference pattern having a highest correlation coefficient is taken to represent the input pattern **10**. A perfect match between the input pattern **10** and a reference pattern (e.g., reference pattern S_i) will yield a correlation value of 1, while lesser degrees of similarity will produce correspondingly lower correlation values. The correlation values provide a basis for determining the reference pattern S_i with the highest probability of being the input pattern **10**.

A drawback in the prior art pattern recognition apparatus **11** is that when the plurality of reference patterns S_1 to S_n include a number of similar patterns, each of these reference patterns produces a high correlation value. This prevents a correct determination of the input pattern **10**. To overcome such drawback, the comparison points of the reference patterns S_1 to S_n can be weighted, or part of the input pattern **10** can be designated as a reference region (not shown). However, since such weighting or reference region techniques relies on human judgement, these techniques are intuitive, trial-and-error, solutions. Moreover, the technique of using weighting for the comparison points of the reference patterns S_1 to $S_n$have to be expressed in terms of multiple values, and are expressed as a pair of values in the prior art apparatuses **11**. This increases the complexity of the calculations and the processing time.

Furthermore, in preparing the reference patterns S_1 to S_n, it is generally assumed that the input pattern **10** is an ideal pattern. However, in practice the input pattern **10** is prone to positional shifts, fading, and so forth which degrades the pattern recognition rate. Thus, there is a need for a pattern recognition apparatus that is capable of achieving a high pattern recognition rate even when the image quality or precision of the input pattern **10** is not very good. Additionally, there is a need for a pattern recognition apparatus that enables the speed of the pattern recognition to be increased by greatly reducing the number of pattern comparison points (evaluation points) that are used.

SUMMARY OF THE INVENTION

The present invention is directed to pattern recognition method and apparatus that judges an input pattern by comparing the input pattern with a plurality of different registered reference patterns. The pattern recognition apparatus comprises probability calculation means, and entropy calculation means. The probability calculation means calculates a probability of the existence of any one of the plurality of reference patterns for each pixel within a prescribed frame surrounding the plurality of pixels forming each one of the reference patterns. The entropy calculation means is responsive to the probability values obtained from the probability calculation means for calculating information content entropy values which are used as a basis for selecting pixels to be used for comparison with corresponding pixels of the input pattern.

In a first aspect of the above-described pattern recognition apparatus in accordance with the present invention, the entropy calculation means comprises calculating means and selecting means. The calculating means is responsive to the probability values obtained from the probability calculation means for calculating information entrophy values. The selecting means is responsive to the calculated information entrophy values for selecting entrophy values above a predetermined value for selecting pixels within the frame of each reference pattern to be used for comparison with corresponding pixels of the input pattern.

In a second aspect of the above described pattern recognition apparatus in accordance with the present invention, the entropy calculation means comprises calculating means, producing means, and selecting means. The calculating means is responsive to the probability values obtained from the probability calculation means for calculating information entrophy values. The producing means is responsive to a distribution of the calculated information entrophy values within a frame for producing a concentration of a predetermined plurality of centroid pixel points with a predetermined number of adjacent surrounding pixels at certain locations within the frame of each of the reference patterns using a K-mean technique. The selecting means is responsive to the location of the plurality of centroid pixel points and the adjacent surrounding pixels for selecting the pixels within the frame of the reference patterns to be used for comparison with corresponding pixels of the input pattern.

The method of pattern recognition in accordance with the present invention compares an input pattern with a plurality

of different registered reference patterns and comprises the following steps. In a first step, a probability of the existence of any one of the plurality of reference patterns is calculated for each pixel within a prescribed frame surrounding the plurality of pixels forming each one of the reference patterns. In a second step, information content entropy values are calculated in responsive to the probability values obtained in the first step for use as a basis for selecting pixels to be used for comparison with corresponding pixels of the input pattern. In a third step, pixels selected in the second step are compared with corresponding pixels in the input pattern for determining which of the plurality of reference patterns provides a closest match with the input pattern.

The invention and its various advantages will be better understood from the following more detailed description taken with the accompanying drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a block diagram of a pattern recognition apparatus in accordance with the present invention;

FIG. **2** shows a flowchart of the operation of a comparison pixel determination section of the pattern recognition apparatus of FIG. **1**;

FIG. **3** shows a graph of a relationship between a number of evaluation points and a number of errors;

FIG. **4** shows a frame of an exemplary reference pattern including a set of delineated pixels with an entropy value above a certain threshold;

FIG. **5** shows a frame of the exemplary reference pattern of FIG. **4** including centroids and surrounding pixel regions derived by a K-mean method;

FIG. **6** shows samples of exemplary distortion-free reference patterns recognized by the pattern recognition apparatus in accordance with the present invention;

FIG. **7** shows samples of exemplary patterns including distortions which are recognized by the pattern recognition apparatus in accordance with the present invention;

FIGS. **8A** and **8B** show two exemplary reference patterns S_a and S_b;

FIG. **8C** shows the difference between the two exemplary reference patterns of FIGS. **8A** and **8B**; and

FIG. **9** shows a block diagram of a general principles of operation of a prior art pattern recognition system.

DETAILED DESCRIPTION

Referring now to FIG. **1**, there is shown a block diagram of a pattern recognition apparatus **30** in accordance with the present invention. The pattern recognition apparatus **30** comprises a comparison pixel determination section **31**, an image data input section **32**, a preprocessor section **34**, a binarizer **36**, an image data memory section **38**, a pattern extraction section **40**, a vectorizer **42**, and input pattern data memory **44**, a vectorizer pattern recognition section **46**, a reference pattern data memory **48**, a comparison judgment section **50**, and a judgment result output section **52**. More particularly, image data is inputted to the image data input section **32**. This data is processed by passing the data through the serial connection of the preprocessor section **34**, the binarizer **36**, the image data memory section **38**, the pattern extraction section **40**, a first input of the vectorizer **42**, the input pattern data memory **44**, a first input of the comparison judgment section **50**, and the judgment result output section **52**. Reference pattern data signals are inputted to both the comparison pixel determination section **31** and to a first input of the vectorizer pattern recognition section **46**. An output from the comparison pixel determination section **31** is coupled to a second input of the vectorizer **42** and to a second input of the vectorizer pattern recognition section **46**. An output from the vectorizer pattern recognition section **46** is coupled to a second input of the comparison judgment section **50** via the reference pattern data memory **48**.

In operation, image data scanned by a CCD or other such image acquisition means is inputted to the preprocessing section **34** via the image data input section **32**. The preprocessing section **34** serves to, for example, remove noise components and adjust the orientation of the image. The image data is then binarized by the binarizing section **36**, stored temporarily in the image data memory **38**, and is then sent to the pattern extraction section **40** which extracts and outputs only the essential input pattern image data, in a prescribed frame.

The input pattern data is then inputted to the first input of the vectorizer **42**. The comparison pixel determination section **31** supplies the second input of the vectorizer **42** with information on the positions of the comparison pixels to be used by the comparison judgment section **50**. The vectorizer **42** converts the input pattern data to evaluation vectors (based on an Equation (4) which is shown and described hereinafter), and the data of the evaluation vectors are stored in the input pattern data memory **44**. Alternatively, although not shown, all of the input pattern data extracted by the pattern extraction section **40** can be stored directly in the input pattern data memory **44** and converted to evaluation vectors by the comparison judgement section **50**. However, the preferred arrangement of storing the evaluation vectors from the vectorizer **42** has the advantage of being able to use a memory with a smaller capacity.

The reference pattern data is retrieved from a memory (not shown) and is inputted to the vectorizer pattern recognition section **46**. Here too, the comparison pixel determination section **31** supplies the vectorizer pattern recognition section **46** with information on the positions of the comparison pixels to be used by the comparison judgment section **50**. The vectorizer pattern recognition section **46** converts the reference pattern data into evaluation vectors (also in accordance with equation (4)), and the evaluation vector data is then stored in a reference pattern data memory **48**.

In the comparison judgment section **50**, the input pattern data evaluation vectors stored in the input pattern data memory **44** are compared with the evaluation vectors of the reference pattern data stored in the reference pattern data memory **48**. The input pattern, as determined from the reference pattern evaluation vectors, that shows the closest match is outputted from the comparison judgment section **50**. The judgement result output section **52** then outputs the result to, for example, a visual display unit (not shown).

The pattern recognition apparatus **30** in accordance with the present invention enables pattern recognition to be speeded up over the prior art pattern recognition apparatus **11** of FIG. **9** by greatly reducing the number of pattern comparison points (evaluation points) that are used to identify an image pattern. More particularly, the pattern recognition apparatus **30** utilizes the following principles in accordance with the present invention.

Referring now to FIGS. **8A**, **8B**, and **8C**, FIG. **8A** shows a first exemplary reference patterns S_a (shown in a cross-hatched triangle) within a prescribed frame **16** comprising a first pixel **18** located outside the reference pattern S_a, and a

second pixel **20** located inside the reference pattern S_a. FIG. **8B** shows a second exemplary reference patterns S_b (shown in a cross-hatched rectangle) within the prescribed frame **16** comprising a first pixel **19** located outside the reference pattern S_b and a second pixel **21** located inside the reference pattern S_b. FIG. **8C** shows information that is of use for recognizing an input pattern [not shown but including one of the patterns of FIGS. **8A** or **8B**], and shows the hatched regions **22** and **24** of the exemplary reference patterns S_a and S_b that are different when the two reference patterns S_a and S_b are superposed. Normally, a comparison of an input pattern (not shown) with the reference patterns S_a and S_b involves an individual comparison of all of the pixels within the area of the frame **16**.

When considering the information content of are outside both of the patterns S_a and S_b, are both the corresponding pixels **18** and **19** within the frame **16** in FIGS. **8A** and **8B**, respectively, the pixels **18** and **19** white in color. Therefore, pixels **18** and **19** do not include information from which a determination of the input pattern can be made from these two reference patterns. Similarly, pixels **20** and **21** of FIGS. **8A** and **8B**, respectively, are inside the respective reference patterns S_a and S_b, are both black in color, and do not include information from which a determination of the input pattern can be made from these two reference patterns. With respect to the two reference patterns S_a and S_b shown in FIGS. **8A** and **8B**, respectively, the information that is of use in recognizing the input pattern is located in the hatched regions **22** and **24** of FIG. **8C** when the two reference patterns S_a and S_b are superposed. For example, an input pattern is recognized as corresponding to the reference pattern S_b of FIG. **8B** if the regions of the input pattern corresponding to the regions **22** in FIG. **8C** are black. Conversely, the input pattern is recognized as corresponding to the reference pattern S_2 of FIG. **8A** if the regions of the input pattern corresponding to the regions **24** in FIG. **8C** are black.

Based on this assumption, pixel information entropy H is defined by the equation:

$$H = \sum_{i=1}^{N} (-Pi \log_2 Pi) \quad (1)$$

where i is an event number, N is the total number of events, and Pi is the probability of the occurrence of the event i. Thus, to calculate the entropy value H of, for example, the pixel **18** of FIG. **8A**, which is white with respect to the reference pattern S_a, the probability for pixel **18** being white is 1.0, and the probability for pixel **18** being black is 0. The same result occurs for pixel **19** of FIG. **8B**. As such, the entropy H for such pixels are calculated from the following equation:

$$H=-1.0 \log_2 (1.0)-0 \log (0)=0 \quad (2)$$

To calculate the entropy H of, for example, pixels **20** and **21** of FIGS. **8A** and **8B**, respectively, which pixels are both black, equation (2) also produces an entropy value of H=0.

It is to be understood that the probability of a pixel existing within the region **22**, or within the region **24**, is ½. For such probability, the pixel entropy H is calculated from the following equation:

$$H=-\tfrac{1}{2}\log_2 (\tfrac{1}{2})-\tfrac{1}{2} \log_2 (\tfrac{1}{2})=1 \quad (3)$$

The entropy H values thus calculated for each of the pixels within areas **22** and **24**, that form the evaluation points for pattern comparison, represent pixel information content for the purpose of pattern recognition. Using only pixels with high entropy values as evaluation points for pattern recognition permits the elimination of evaluation points that are not needed for comparison purposes (e.g., outside regions **22** and **24**).

Other advantages of pattern recognition based on the use of high entropy points are now examined from a different perspective. As in the typical prior art arrangements, here a two-dimensional evaluation vector, R=(X, Y), is introduced. For the evaluation vector R, X stands for the region **22** of FIG. **8C**, and it is assumed that X=1 when the region **22** is black and X=0 when the region **22** is white. Similarly, Y stands for the region **24**, and it is assumed that Y=1 when the region **24** is black and Y=0 when the region **24** is white.

When examining region **22** and region **24** with respect to an input pattern, the input pattern can be recognized as corresponding to the reference pattern S_b of FIG. **8B** when the two-dimensional evaluation vector R=(1, 0). Similarly, the input pattern can be recognized as corresponding to the reference pattern S_a of FIG. **8A** when the two-dimensional evaluation vector R=(0, 1). Regarding the direction of the two-dimensional evaluation vectors R, it is readily understood that the above two terms are orthogonal. That is, using high entropy points for the pattern recognition makes it possible to achieve two-dimensional evaluation vectors R with good orthogonality. In other words, it results in a pattern recognition process that uses only the information that is truly useful. In the pattern recognition apparatus **30** of FIG. **1**, an entropy value H is calculated for each pixel by the comparison pixel determination section **31**. This entropy value is then used as a basis for determining whether or not a predetermined pixel in the frame **16** is to be used as an evaluation point in the pattern recognition operation.

Referring now to FIG. **6**, there is shown exemplary reference patterns for the numerals **0** to **9**. It is assumed hereinafter that the pattern recognition apparatus **30** of FIG. **1** is used for recognizing an input pattern comprising one of the numerals **0** to **9** shown in FIG. **6**. Input patterns are generally considered to have relatively little distortion, but in practice it has been found that the binarization process described hereinbelow can result in images that are displaced or defaced. When the input patterns are alphanumeric characters, the starting point of characters are often subjected to displacement, rotation and other such positional shifts.

Referring now to FIG. **7**, there is shown samples of reference patterns that can be recognized by the pattern recognition apparatus **30** of FIG. **1**. More particularly, in accordance with the present invention, not only are reference patterns prepared that are clear and essentially free of distortion as shown in FIG. **6**, but versions of the reference patterns **0** to **9** that include slight distortions are also prepared. For exemplary purposes only, it is assumed hereinafter that sixteen variant versions of each of the reference patterns of **0** to **9** shown in FIG. **6** are prepared, or a total of 160 reference patterns. It is through these variant versions of the reference patterns **0** to **9** that image patterns which include displacement, rotation and other such positional shifts are recognized by the pattern recognition apparatus **30** of FIG. **1**.

Referring now to FIG. **2**, there is shown a flowchart of the operation of the comparison pixel determination section **31** in the pattern recognition apparatus **30** of FIG. **1**. In a first step designated by block **101** (following a "start" block **100**), data relating to the 160 variant reference patterns (discussed hereinabove) is read out of a memory (not shown in FIG. **1**) and provided as an input to the comparison pixel determination section **31**. In a second step designated by block **102**,

the probability [P_i of equation (1)]is calculated for each pixel within a frame **16** (of FIG. **6**) that contains a reference pattern being black or white. In a third step designated by block **103**, the probability of each pixel being black or white, as calculated in block **102**, is used to calculate the information content entropy value H, using equation (1). The function of block **103** is better understood from FIG. **4**.

Referring now to FIG. **4**, there is shown pixel entropy values H thus obtained for the 160 variant reference patterns. An examination of FIG. **4** shows that pixels with high entropy values are concentrated at or near the center, while the probability of black pixels near the edges is relatively low.

Returning now to FIG. **2**, in a fourth step designated by block **104**, pixels with high entropy values are extracted from the entropy values H obtained in the third step indicated by block **103**. In a fifth step designated by block **105**, a proximity region is set as is explained hereinbelow. In a sixth step designated by block **106**, the output coordinates of each comparison point is provided before the operation of the comparison pixel determination section **30** is exited via block **107**. The output coordinates of the comparison pixels from block **106** are provided as inputs to the vectorizer section **42** and the vectorizer pattern recognition section **46** of FIG. **1**.

The fourth step designated by block **104** in FIG. **2** can be done in a number of ways. One way is that used to produce a region **200** of FIG. **4**, which is produced by a straight extraction of entropies of 0.9 and above, and designating any pixel with an entropy of 0.9 or more as an evaluation point. From the 468 entrophy values shown in the 18-by-26 entrophy value matrix of FIG. **4**, the straight extraction of entropies of 0.9 or above results in the designation of just 207 pixels as evaluation points or pixels. The resulting 207 evaluation points roughly halves the number of comparison pixels used by the prior art method (which uses all 468 pixels) for comparison purposes. This greatly reduces the number of calculations involved.

Another technique involves taking into account the entropy distribution over the whole frame. There is for example the K-mean technique as described, for instance, on page 250 of the book entitled "Pattern Classification and Scene Analysis" by Duda and Hart. In the K-mean technique, the entropy space shown in FIG. **4** consists of twenty-four small regions (not shown), each of the same size, and an entropy centroid (central pixel) of each of these small regions is calculated from the entropy values of the pixels and the distance from the centroid. The frame of 468 pixels is then redivided into twenty-four small regions each consisting of one of the above twenty-four centroids and the closest surrounding pixels. This is readily ascertained by calculating the distance between the twenty-four centroids and each pixel. The centroid of each of those twenty-four regions is then again obtained, and the frame of 468 pixels is again divided into small regions each centering on one of those newly obtained centroids. Repeating this process gradually produces a concentration of centroid points at certain locations.

Referring now to FIG. **5**, there is shown a plurality of 24 centroids **202** obtained from the K-mean technique as explained hereinabove. Thus, the derivation of these twenty-four centroids **202** (each shown as a single two or three digit number with a rounded edge rectangle therearound) is not based simply on their having a high entropy value, but instead also takes into account the entropies of the surrounding pixels. However, recognition evaluation processing based only on such centroids can be greatly influenced by, for example, noise elements that cause a loss of pixel data corresponding to a centroid, or by a one-pixel shift extending over an entire input pattern.

In accordance with the present invention, a proximity region **204** measuring 3-by-3 pixels is established for each of the centroids **202**, and the sum of the pixels of each of the proximity regions **204** is used as the representative value of the region's centroid. This proximity region is set in the fifth step of FIG. **2** as is shown by block **105**.

As is now described, the orthogonality of the two-dimensional evaluation vectors R is utilized for the comparison of an input pattern and the reference patterns. As such, the two-dimensional evaluation vectors R derived from the calculated entropies shown in FIG. **5** have twenty-four elements r, each element r having a value between 0 and 9 that is the sum of the pixels of each proximity region **204**. This is expressed by the following equation:

$$R=(r_1, r_2, \ldots, r_{24}) \quad (4)$$

where r has a value of from 0 to 9. The reason for the **24** small regions when using the K-mean method will now be explained.

Referring now to FIG. **3**, there is shown a graph of a relationship between a number of evaluation points and a number of errors obtained by experimentation. FIG. **3** shows that under the conditions used in the present invention, errors were fewest when the number of evaluation points is around 30. More evaluation points results in more non-essential information being processed, hence producing a slight increase in the number of errors. The number of evaluation points is set at 24, since it is close to 30. Experiments using 3-by-3 and 5-by-5 proximity regions, indicated a preferred use of the 3-by-3 configuration. A 5-by-5 configuration increased the amount of overlap among adjacent regions. The 5-by-5 configuration lowered the pattern recognition rate. The resultant coordinates of the twenty-four comparison pixels are determined and outputted to the prescribed vectorizer pattern recognition section **46** and vectorizer section **42** (as shown in step **106** of FIG. **2**).

A characteristic feature of the present invention is (a) the use of information content entropy values to determine the comparison pixels, and (b) the processing operation of the comparison judgement section **50** which can be adapted to various techniques in conventional use.

It is to be appreciated and understood that the specific embodiments of the invention described hereinabove are merely illustrative of the general principles of the invention. Various modifications may be made by those skilled in the art which are consistent with the principles set forth. For example, the comparison judgment method used by the comparison judgement section **50** may be any one of the various methods in conventional use (i.e., the centroids **202** of the typical variant reference patterns shown in FIG. **5** may be converted to evaluation vectors R). These evaluation vectors are then averaged to produce standard data. Pattern recognition is then performed on the basis of the correlation between this standard data and the input patterns. Alternatively, any suitable neural network that has been developed in recent years can be utilized to obtain the reference pattern evaluation vectors. This knowledge is then stored in the comparison judgement section **50** for use by the pattern recognition process. Still further, it is also possible to use the high orthogonality of the entropy evaluation vectors R, described hereinbefore, by applying orthogonal transforms to the comparison of the input pattern and the reference patterns. This technique involves selecting a plurality of representative reference pattern evaluation vectors to form a

correlation matrix, and applying a KL (Karhunen-Loive) transform to the matrix. The resultant KL transform coefficients are then used to produce standard reference pattern data. Using up to three-dimensional KL transform coefficients, it is possible to achieve a recognition rate of over 99.9% in the case of the numeric characters 0 to 9 shown in FIG. 6. Furthermore, while the invention has been described with reference to a two-dimensional image spatial plane, this is not limitative, as entropy values can be applied with respect to characteristic pattern quantities.

What is claimed is:

1. A pattern recognition apparatus for comparing an input pattern with a plurality of different registered reference patterns comprising:

probability calculation circuit means for calculating a probability of the existence of a pixel of any one of the plurality of different registered reference patterns at each pixel within a prescribed frame of MxN pixels separately forming each one of the reference patterns;

entropy calculation circuit means responsive to the probability values obtained from the probability calculation means for calculating pixel information content entropy values for each of the pixels within the prescribed frame, and using said entropy values as a basis for selecting a number of pixel points in the prescribed frame which is less than M times N to be used for comparison with corresponding pixel points of the input pattern, wherein the entropy calculation means comprises means responsive to the probability values obtained from the probability calculation means for calculating information entropy values means responsive to a distribution of the calculated information entropy values within a frame for producing a predetermined plurality of centroid pixel points with a predetermined number of adjacent surrounding pixels at certain locations within the frame of the reference patterns using a K-mean technique and selecting means responsive to the location of the plurality of centroid pixel points and the adjacent surrounding pixels for selecting the pixels within the frame of the reference patterns to be compared with corresponding pixels of the input pattern;

first vectorizing means responsive to data regarding pixels of the input pattern for converting positions of the pixels in the input pattern, corresponding to the pixels selected by the selecting means, into first evaluation vectors;

second vectorizing means responsive to data regarding pixels of each reference pattern for converting positions of the pixels in the plurality of reference patterns, corresponding to the pixels selected by the selecting means, into second evaluation vectors; and

comparator circuit means for comparing the first and second evaluation vectors and generating an output signal indicating which of the plurality of reference patterns has a highest probability of being the input pattern.

2. A pattern recognition apparatus for comparing an input pattern with a plurality of different registered reference patterns comprising:

probability calculation circuit means for calculating a probability of the existence of a pixel of any one of the plurality of different registered reference patterns at each pixel within a prescribed frame of MxN pixels separately forming each one of the reference patterns;

entropy calculation circuit means responsive to the probability values obtained from the probability calculation means for calculating pixel information content entropy values for each of the pixels within the prescribed frame, and using said entropy values as a basis for selecting a number of pixel points in the prescribed frame which is less than M times N to be used for comparison with corresponding pixel points of the input pattern, wherein the entropy calculation means comprises means responsive to the probability values obtained from the probability calculation means for calculating information entropy values, and Selecting means responsive to the calculated pixel information entropy values for selecting entropy values above a predetermined value for selecting pixels within the frame of the plurality of different reference patterns to be used for comparison with corresponding pixels of the input pattern;

first vectorizing means responsive to data regarding pixels of the input pattern for converting positions of the pixels in the input pattern, corresponding to the pixels selected by the selecting means, into first evaluation vectors;

second vectorizing means responsive to data regarding pixels of the plurality of reference patterns for converting positions of the pixels in the plurality of reference patterns, corresponding to the pixels selected by the selecting means, into second evaluation vectors; and

comparator circuit means for comparing corresponding ones of the first and second evaluation vectors and determining which of the reference patterns provides a highest probability of being the input pattern.

3. A pattern recognition apparatus comprising:

means for receiving an input pattern which is defined with a frame of MxN pixels;

means for receiving a plurality of different reference patterns where each reference pattern is defined within a frame of MxN pixels and at least one of the reference patterns includes a representation of the input pattern;

probability calculation circuit means for calculating a probability of the existence of any one of the plurality of reference patterns at each pixel within the prescribed frame separately forming each one of the reference patterns;

entropy calculation circuit means responsive to the probability values calculated by the probability calculation means for calculating pixel information content entropy values for each of the pixels within the prescribed from of the plurality of reference patterns, and determining from the entropy values for all of the different registered reference patterns which of the calculated pixel information content entropy values provide a basis for selecting a number of pixel points in the prescribed frame which is less than M times N for comparing corresponding pixel points of the input pattern and each of the reference patterns; and

comparator circuit means for comparing the selected pixels determined to provide a basis for comparison for each of the reference patterns by the entropy calculation means with corresponding pixels of the input pattern, and generating an output signal indicating which one of the plurality of reference patterns has a highest probability of being the input pattern;

wherein the entropy calculation circuit means comprises means responsive to the probability values obtained from the probability calculation means for calculating pixel information entropy values, means responsive to a distribution of the calculated pixel information

entropy values within a frame for producing a predetermined plurality of centroid pixel points with a predetermined number of adjacent surrounding pixels at certain locations within the frame of each of the reference patterns using a K-mean technique, and selecting means responsive to the location of the plurality of centroid pixel points and the adjacent surrounding pixels for selecting the pixels within the frame of the reference patterns to be used by the comparator for comparison with corresponding pixels of the input pattern; and

further comprising first vectorizing means responsive to data regarding pixels of the input pattern for converting positions of the pixels in the input pattern, corresponding to the pixels selected by the selecting means, into first evaluation vectors; and

second vectorizing means responsive to data regarding pixels of each reference pattern for converting positions of the pixels in the plurality of reference patterns, corresponding to the pixels selected by the selecting means, into second evaluation vectors;

wherein the comparator circuit means compares corresponding ones of the first and second evaluation vectors and determines which of the reference patterns provides the highest probability of being the input pattern.

4. A pattern recognition apparatus comprising:

means for receiving an input pattern which is defined with a frame of MxN pixels;

means for receiving a plurality of different reference patterns where each reference pattern is defined within a frame of MxN pixels and at least one of the reference patterns includes a representation of the input pattern;

probability calculation circuit means for calculating a probability of the existence of any one of the plurality of reference patterns at each pixel within the prescribed frame separately forming each one of the reference patterns;

entropy calculation circuit means responsive to the probability values calculated by the probability calculation means for calculating pixel information content entropy values for each of the pixels within the prescribed from of the plurality of reference patterns, and determining from the entropy values for all of the different registered reference patterns which of the calculated pixel information content entropy values provide a basis for selecting a number of pixel points in the prescribed frame which is less than M times N for comparing corresponding pixel points of the input pattern and each Of the reference patterns; and

comparator circuit means for comparing the selected pixels determined to provide a basis for comparison for each of the reference patterns by the entropy calculation means with corresponding pixels of the input pattern, and generating an output signal indicating which one of the plurality of reference patterns has a highest probability of being the input pattern;

wherein the entropy calculation means comprises means responsive to the probability values obtained from the probability calculation means for calculating pixel information entropy values, and selecting means responsive to the calculated pixel information entropy values for selecting entropy values above a predetermined value for selecting pixels within the frame of the plurality of different reference patterns to be used by the comparator circuit means for comparison with corresponding pixels of the input pattern; and

further comprising first vectorizing means responsive to data regarding pixels of the input pattern for converting positions of the pixels in the input pattern, corresponding to the pixels selected by the selecting means, into first evaluation vectors;

second vectorizing means responsive to data regarding pixels of each reference pattern for converting positions of the pixels in the plurality of reference patterns, corresponding to the pixels selected by the selecting means, into second evaluation vectors; and

wherein the comparator circuit means compares corresponding ones of the first and second evaluation vectors and determines which of the reference patterns provides the highest probability of being the input pattern.

5. A method of providing pattern recognition in a pattern recognition apparatus that compares an input pattern with a plurality of different registered reference patterns comprising the steps of:

(a) calculating in a probability calculation device a probability of the existence of any one of the plurality of reference patterns at each pixel within a predescribed frame of MxN pixels separately forming each one of the reference patterns;

(b) calculating in a comparison pixel determination device separate information content entropy values for the pixels within the prescribed frame of the reference patterns in response to the probability values obtained in step (a) for use as a basis for selecting a number of pixels in the prescribed frame of the reference patterns which is less than M times N to be used for comparison with corresponding pixels of the input pattern;

wherein step (b), performed in the comparison pixel determination device, comprises the substeps of: (b1) calculating pixel information entropy values from the probability values obtained in step (a); and (b2) selecting pixel information entropy values from step (b1) which are above a predetermined value for selecting pixels within the frame of the plurality of reference patterns to be used for comparison with corresponding pixels of the input pattern;

(c) converting positions of the pixels in the input pattern corresponding to the pixels selected in step (b) into first evaluation vectors;

(d) converting positions of the pixels in the plurality of reference patterns corresponding to the pixels selected in step (b) into second evaluation vectors; and

(e) comparing corresponding ones of the first and second evaluation vectors in a comparator device and determining which of the reference patterns provides the highest probability of being input pattern.

6. A method of providing pattern recognition in a pattern recognition apparatus that compares an input pattern with a plurality of different registered reference patterns comprising the steps of:

(a) calculating in a probability calculation device a probability of the existence of any one of the plurality of reference patterns at each pixel within a predescribed frame of MxN pixels separately forming each one of the reference patterns;

(b) calculating in a comparison pixel determination device separate information content entropy values for the pixels within the prescribed frame of the reference patterns in response to the probability values obtained in step (a) for use as a basis for selecting a number of pixels in the prescribed frame of the reference patterns

which is less than M times N to be used for comparison with corresponding pixels of the input pattern;

wherein step (b), performed in the comparison pixel determination device, comprises the substeps of: (b1) calculating pixel information entropy values from the probability values obtained from step (a); (b2) producing a predetermined plurality of centroid pixels with a predetermined number of adjacent surrounding pixels at certain locations within the frame of the plurality of reference patterns using the frame of each of the reference patterns using a K-mean technique from distribution of the calculated pixel information entropy values within a frame obtained from step (b1); and (b3) selecting the pixels within the frame of the reference patterns to be used for comparison with corresponding pixels of the input pattern dependent on the location of the plurality of centroid pixels and the adjacent surrounding pixels obtained in step (b2);

(c) converting positions of the pixels in the input pattern corresponding to the pixels selected in step (b3) into first evaluation vectors;

(d) converting positions of the pixels in the plurality of reference patterns corresponding to the pixels selected in step (b3) into second evaluation vectors; and

(e) comparing corresponding ones of the first and second evaluation vectors in a comparator device and determining which of the reference patterns provides the highest probability of being input pattern.

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